

# **A THREE DIMENSIONAL RECONSTRUCTION ALGORITHM FOR ROTATIONALLY SCANNED OBJECTS**

An Undergraduate Research Scholars Thesis

by

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# **ABSTRACT**

**A Three Dimensional Reconstruction Algorithm for Rotationally Scanned Objects  
(May 2014)**

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Ultrasound imaging is a medical modality that uses high frequency sound waves to produce high resolution images of internal tissues' structures. Since ultrasound images are captured in real time, the modality provides a refined method to analyze internal organs such as liver, kidney and heart. Ultrasound imaging is relatively inexpensive and safe compared to other imaging modalities. So, it is used for diagnosis of a wide range of diseases.

One of the emerging techniques in the ultrasound imaging field is three-dimensional (3D) imaging. Typically, ultrasound transducer arrays are used to capture 2D views of the tissue under investigation. 2D images can be clinically useful. However, it is sometimes difficult to visualize the entire surface of an organ or tissue's abnormalities using only 2D images. Additionally, 2D images can be difficult to interpret. Therefore, obtaining 3D volumes or snapshots of the tissue of interest can greatly help the diagnosis of diseases or abnormalities. Creating 3D volumes may be a very useful tool in clinical practices and is often used in obstetrics, cardiology, cancer imaging and image-guided surgeries.

In order to generate 3D volumes, a set of 2D ultrasound images needs to be acquired first. The 2D images can be obtained using an imaging probe capturing the tissue from different angles. Then, a reconstruction algorithm is applied to the data to produce a 3D volume. This thesis focuses on the development and analysis of a 3D reconstruction algorithm that uses 2D ultrasound images acquired from a tissue that is been scanned rotationally with the transducer. The algorithm is validated using experimental data obtained from phantoms of known geometry. The results of this thesis show that the proposed algorithm can be used to reconstruct 3D volumes of the controlled phantom with high accuracy. While more experiments are needed to fully understand the limitations of the algorithm, these preliminary results suggest that, in the future, this algorithm may also be used for 3D imaging of biological tissues.

## **DEDICATION**

I dedicate this research to my parents. Without their continuous support and help this opportunity would not have been possible.

## **ACKNOWLEDGEMENTS**

For most, I would like to express my deepest gratitude to Dr. Raffaella Righetti for giving me this incredible opportunity and her continuous support, immense knowledge and patience. Throughout this research, I have learned many new skills. I would also like to thank her for helping me to shape my interest and ideas.

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I would also like to thank Lucas Stephen Kimble for all his help throughout collecting data, writing the algorithm and supporting me in the lab. He has been so helpful to me when I needed him.

And lastly, my appreciation and friendship goes to Severiano Mata, who helped me in making samples for collecting data. He has always been a great support in my struggles and willing to give help.

## **NOMENCLATURE**

|     |                             |
|-----|-----------------------------|
| US  | Ultrasound                  |
| 2D  | 2 Dimensional               |
| 3D  | 3 Dimensional               |
| RGB | Red-Green-Blue triple color |

# **CHAPTER I**

## **INTRODUCTION**

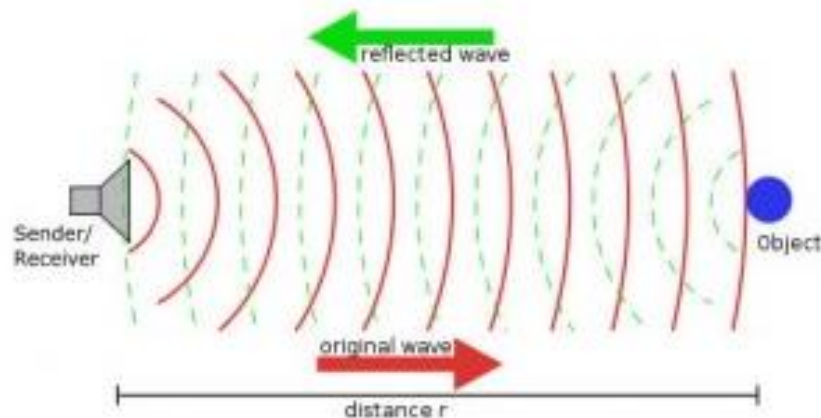
Biomedical imaging is a reliable method for visualizing anatomic structure and determining biological functions within the organs. Ultrasound is one of the most widely used biomedical imaging modality for examinations and diagnosis of a large number of diseases in the world. Ultrasound imaging features include: low cost, durability, portability, safety (radiation-free) and high spatial and temporal resolutions.

The origin of medical ultrasound imaging could be traced back half a century, and tremendous improvements have been made in this field since then. Ultrasound is capable of providing cross-sectional views of anatomical structures with high spatial and temporal resolutions and is typically used in obstetrics, gynecology and cardiology. However, due to its flexibility and non-invasive nature, it has recently become one of the main biomedical imaging tools also for detecting kidney and liver diseases, musculoskeletal abnormalities and cancers. In the last decade, image quality of ultrasound images has improved significantly, and it is now possible to obtain accurate information on blood flow and minute changes in tissues' structures. These advancements in the field have progressively left a great impact on radiology and image-guided therapies as well.

Propagation of ultrasound in tissues produces echoes that can be captured and used to identify the inner structure of a tissue. During an examination, an ultrasonic transducer is used to acquire data from the tissue of interest. This transducer releases sound and captures the waves reflected

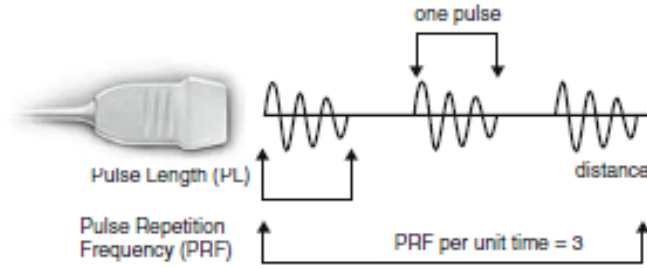


by the various tissue interfaces encountered while the sound wave propagates in the body. These echoes are used to form live images of the organs that are being examined.<sup>(7)</sup> Each section has a different acoustic impedance, which affects the sound reflection.



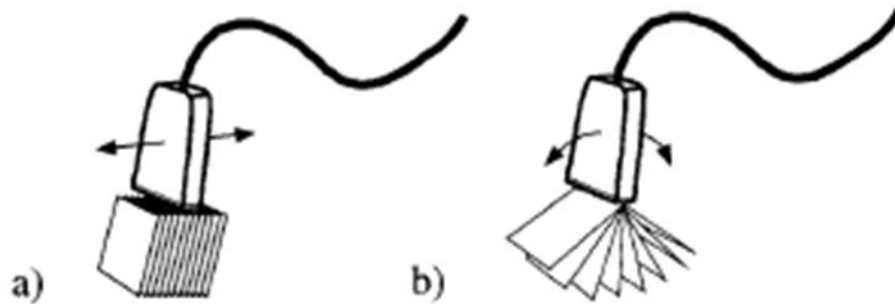
**Figure 1:** Ultrasound waves bounce back to the transducer to create an echo.<sup>(10)</sup>

In a typical US medical examination, the ultrasound transducer captures a series of 2D ultrasound images as the device is swept along the surface of the body. The radiologist who needs to interpret the 2D images to identify the presence of tissue's abnormalities needs to create a 3D subjective impression from prior knowledge of the anatomy and pathology of the organ. "Mentally transforming multiple 2D images from a 3D impression of the anatomy and pathology is not only time-consuming and inefficient, but is also more importantly, variable and subjective, which can lead to incorrect decisions in diagnosis, and in the planning and delivery of therapy."<sup>(3)</sup>



**Figure 2:** Representation of the transducer pulse generation and reflection.<sup>(1)</sup>

Application of 3D reconstruction techniques from a set of 2D images allows visualization of a volume of data and thus can provide additional information about the organ under investigation. 3D ultrasound imaging is in general a much more accurate way to visualize the anatomy than 2D imaging, and it is also more flexible as it allows visualizations of tissue's structures from many points of view.



**Figure 3:** Schematic of transducer showing two types of scanning movements. Diagram a. represents linear scanning and b. demonstrates tilt scanning approach. The collected images from these approaches are used for 3D reconstruction.<sup>(3)</sup>

3D ultrasound imaging can be achieved in different ways. One way is to use a special volume probe (3D transducer). A second way is to sweep across the area of interest to collect a large stack of 2D images and then perform a 3D reconstruction. Typically, 3D reconstruction

algorithms use 2D images obtained along a plane in the free hand acquisition mode, and then combining all the slices to perform a volume rendering of the acquired data.<sup>(8)</sup>

This research aims at developing and analyzing the performance of an algorithm able to perform a 3D reconstruction from a set of 2D ultrasound images obtained at different insonicating angles. The algorithm is tested using experimental ultrasound data obtained from a phantom containing an object of a known shape. The reconstructed 3D volumes are validated with respect to the actual dimensions of the object. In the future, this algorithm may be used for volumetric visualization and assessment of real tissues.

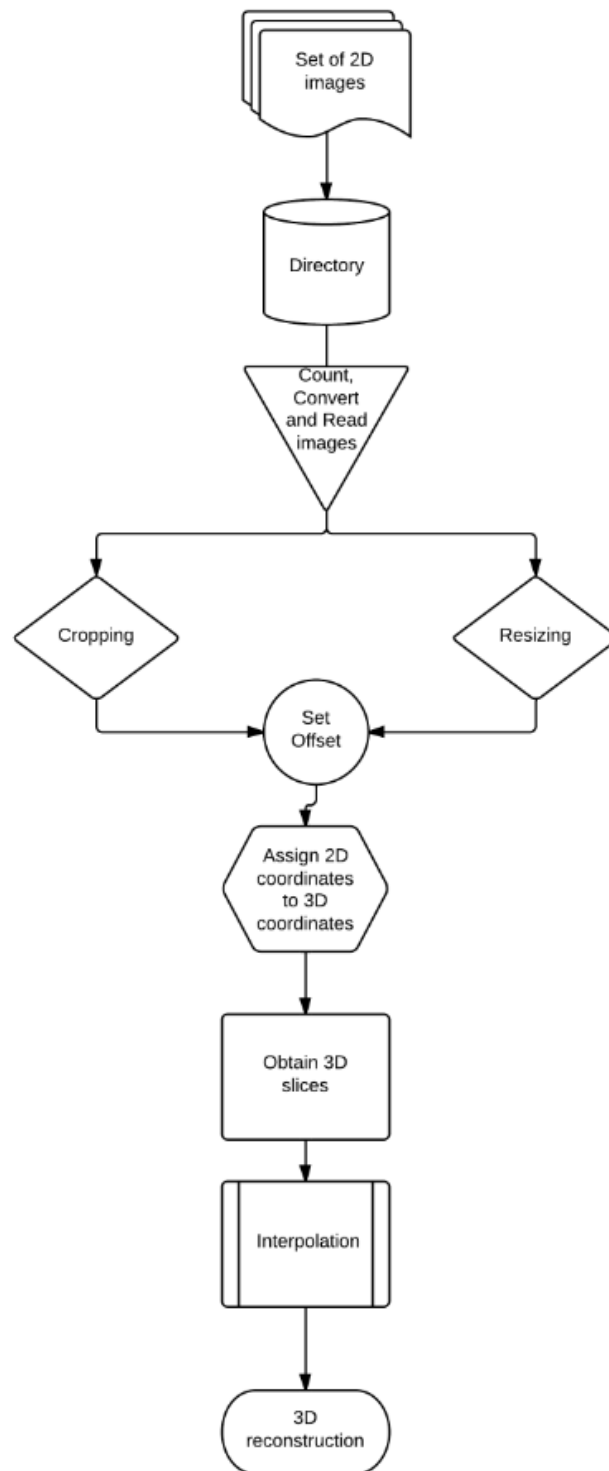
## **CHAPTER II**

### **METHODS**

In this section, the technical details of the proposed 3D reconstruction algorithm and the experimental methodology used to test the proposed algorithm are reported.

#### **The 3D Reconstruction Algorithm**

A number of algorithms for reconstructing 3D volumes from 2D ultrasound images have been reported in the past but most of them are not suitable for 2D images acquired at different insonicating angles. The 3D reconstruction algorithm proposed in this thesis uses 120 2D ultrasound images acquired by rotating an ultrasound transducer around the object of interest (details on the data acquisition method are described in the next section). This algorithm is composed of multiple steps as demonstrated by its flow chart:

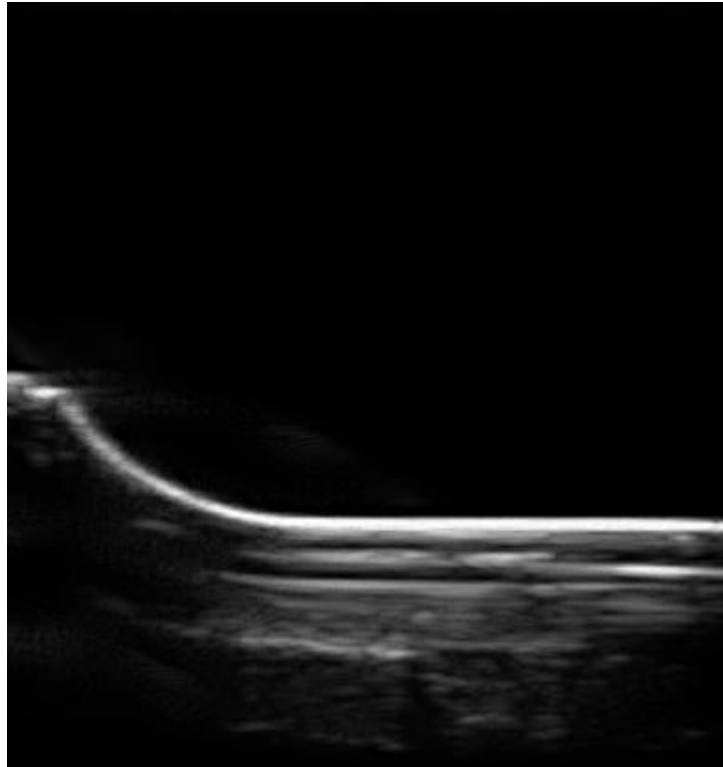


**Figure 4:** Flow chart of the proposed 3D reconstruction algorithm.



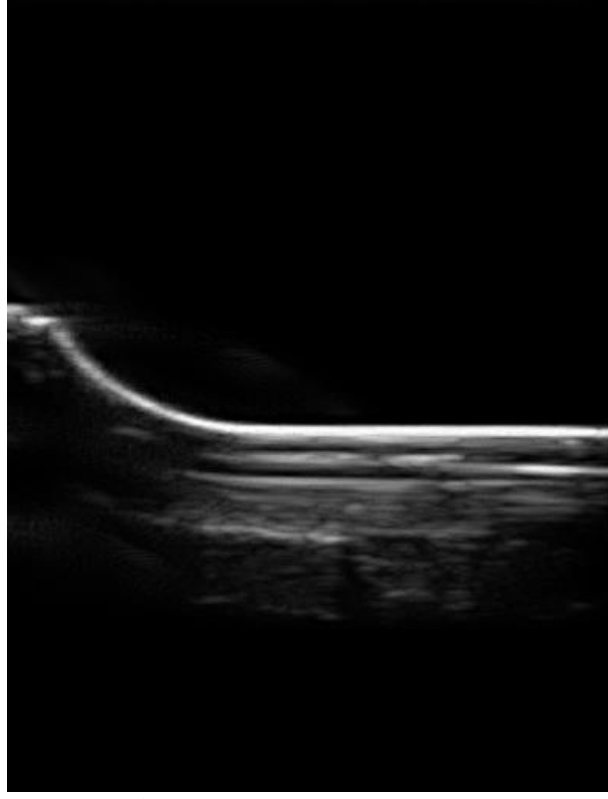
**Figure 5:** Typical B-mode image obtained from the saw handle at  $0^\circ$ .

1. The entire algorithm is written in Matlab. The process begins by counting each image corresponding to a given captured angle in a FOR loop. First, all the collected images are saved in a directory to be accessed during computation. Second, the directory is identified to read all the images. In addition, all the images are converted from true color image RGB to a grayscale intensity image. This process helps to eliminate the saturation information while retaining the luminance. A typical captured image (figure 5) contains text with information regarding the captured image that needs to be eliminated. In order to use only the actual ultrasound data, a cropping function is used to crop the object image. All the cropped images are then saved in a new directory.



**Figure 6:** Cropped image at  $0^\circ$ .

2. To ensure the accuracy of the object location, a fixed offset is identified and used for all the images. The offset is the distance from the center of the phantom to the transducer's face. This offset varies from image to image depending on the geometry of the object. To incorporate the offset into the images, centimeter to pixel calculation is utilized for image adjustment in pixel environment. This provides uniform sized images for the reconstruction. In order to set up each image on a uniform offset; rows and columns of each image as well as the offset are defined as matrices. If the image does not fit the offset, it is cropped from the top to be fitted in the offset matrix. Then, the location of a new matrix is defined. All the new offset images are saved in a new directory. Figure 6 shows a cropped image, which is fitted in the offset.



**Figure 7:** Offset image at 0°.

3. All the offset images are resized to  $\frac{1}{4}$  of the offset image size, which speeds up the overall process of reconstruction without affecting the resolution significantly. Each image is processed in another FOR loop. Starting from image one, each image is swept along its height from the bottom of the image to the top, beginning at the left most side and moving across the image width, by placing each pixel in the 2D image and assign that coordinates to its corresponding 3D coordinates. For each 3D point, the voxel value is calculated using interpolation and following this equation:

$$\begin{aligned}
 x_{new} &= r \cos \theta & y_{new} &= r \sin \theta & z_{new} &= z_{old} \\
 0 < r < image\ height & & 0 < z_{old} < image\ width & & \\
 final_{image}(x_{new}, y_{new}, z_{new}) &= image(x, y)
 \end{aligned}$$



Where  $x_{new}$ ,  $y_{new}$ ,  $z_{new}$  are the new coordinates in the 3D environment. Each coordinate is defined based on the angle  $\theta$  (in this case 3 degrees) as each image is swept along its height and width.

4. In the next step, all the 2D images previously cropped and placed in the 3D matrix enter the interpolation phase. This algorithm removes singleton dimensions, uses a cubic spline interpolation and isosurface to create the reconstructed surface. The spline interpolation was used to create a smooth surface since it possesses a high degree of smoothness at the places where the images are connected in the 3D grid.

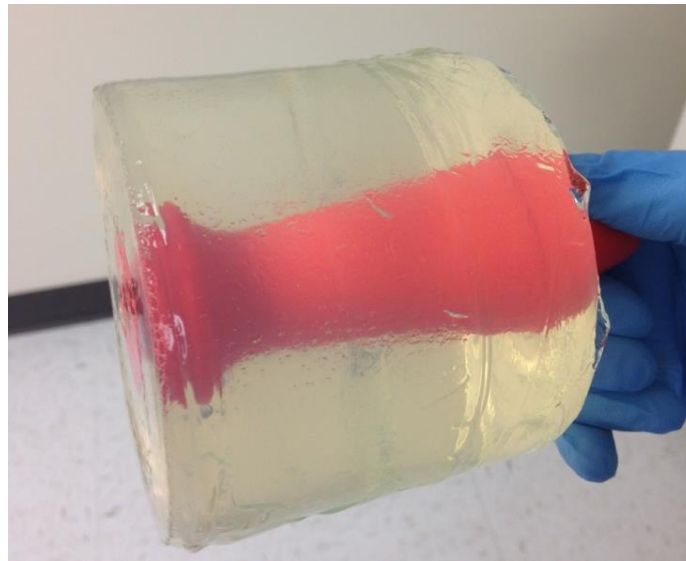
This approach should preserve the original information in the captured images. As the algorithm sweeps across each column and row of 120 images, the 3D volume is reconstructed from the 2D images' pixels. Therefore, by taking any cross section of the 3D volume, the original 2D image can be recovered.

## **Experiments**

Assessing the feasibility of an algorithm requires controlled experimental data. In this case, a phantom object was used so that the corresponding 3D reconstruction could be validated with the object's actual physical dimensions. Four sets of experiments were performed. For every experiment, 120 images were captured while rotating the ultrasound transducer around the phantom with a gap of 3 degrees between successive images.

## Sample Preparation

A saw handle embedded in a clear gelatin phantom was used as a testing object to validate the developed 3D reconstruction algorithm (see figure 8). This phantom allowed to test the algorithm in controlled conditions and to acquire multiple sets of data for analysis.

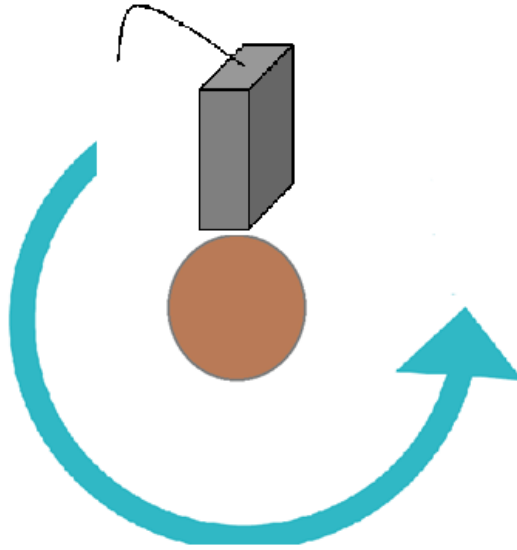


**Figure 8:** The gelatin phantom containing a saw handle used for experimental validation of the proposed 3D reconstruction algorithm

## Rotational Mechanical Scanning Framework

In order to collect the images, a conventional high frequency ultrasound transducer was rotated around the object of interest, and 120 2D ultrasound images were captured at every 3 degrees during the rotation. This forms a set of images radial to the axis of the object. Every captured image represents a view of the object at a different angle. Since the gap between successive images was set at 3 degrees and 120 images were acquired, each set of 2D images represented a

complete 360° rotation around the phantom. As the transducer was moved across the surface of the object, the transducer location corresponding to each captured image was recorded.



**Figure 9:** Schematic of transducer full 360° rotation and demonstration of the transducer location on the object.

### Ultrasound Data Collection

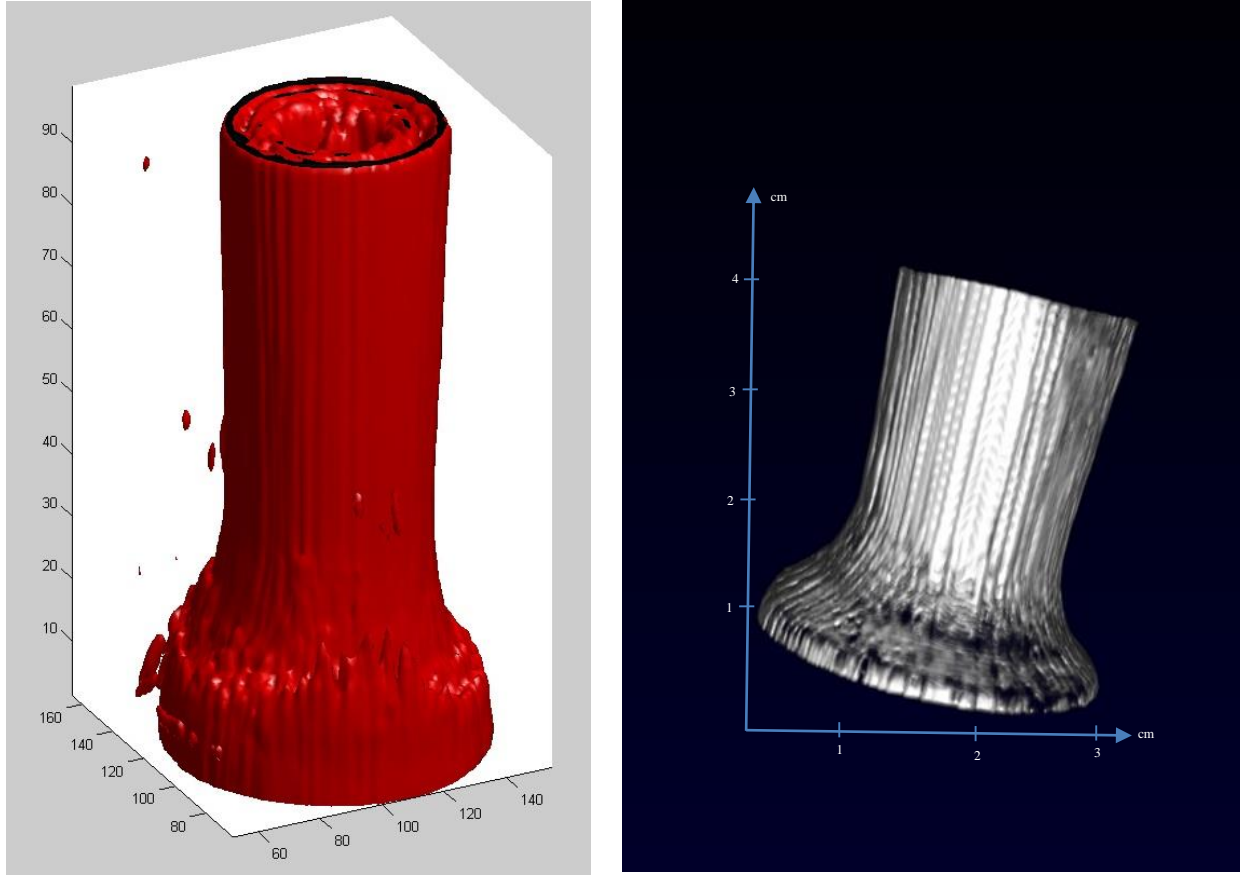
The phantom was scanned using a Sonix RP diagnostic ultrasound system (Ultrasonix Medical Corp., Richmond, BC, Canada) available in the Ultrasound Imaging Laboratory at Texas A&M University. This system uses a 38 mm real-time linear array transducer with 128 channels, 5-14 MHz bandwidth, 50% fractional bandwidth at -6 dB, sampling frequency of 40 MHz, and 1 mm beamwidth at the focus. Acquisitions were performed using a transmission frequency of 10 MHz. No significant attenuation was observed in the visualization of the object's surface when using ultrasonic signals in this frequency band. The focal spot was set at the location of the object's surface and adjusted for each acquired image.

Once the experimental data were collected, the 3D reconstruction algorithm previously explained was applied to visualize the volume of the object contained in the gelatin phantom.

## **CHAPTER III**

### **RESULTS**

The results of a 3D reconstruction obtained using the experimental ultrasound images acquired from the phantom are shown in figure 10. The 3D reconstruction shows only the lower portion of the saw handle because the transducer's face is limited to 4 cm, which defines the lateral width of each captured image. So, the height of the reconstructed image corresponds to the length of the transducer's face. From the 3D reconstruction, the height of the handle was measured to be about 4cm and the diameter to be about 3cm at the widest point, which corresponds to the base of the object.



**Figure 10:** Reconstructed volume of the saw handle.

Image below displays the physical dimensions of the saw handle used for the experiments. A measurement ruler is shown next to the saw handle to show the actual dimensions of the object. These dimensions are: 12 cm height and 3 cm diameter at the widest point. Therefore, there appears to be a good agreement between the 3D reconstructed object and the actual physical dimensions of the object.

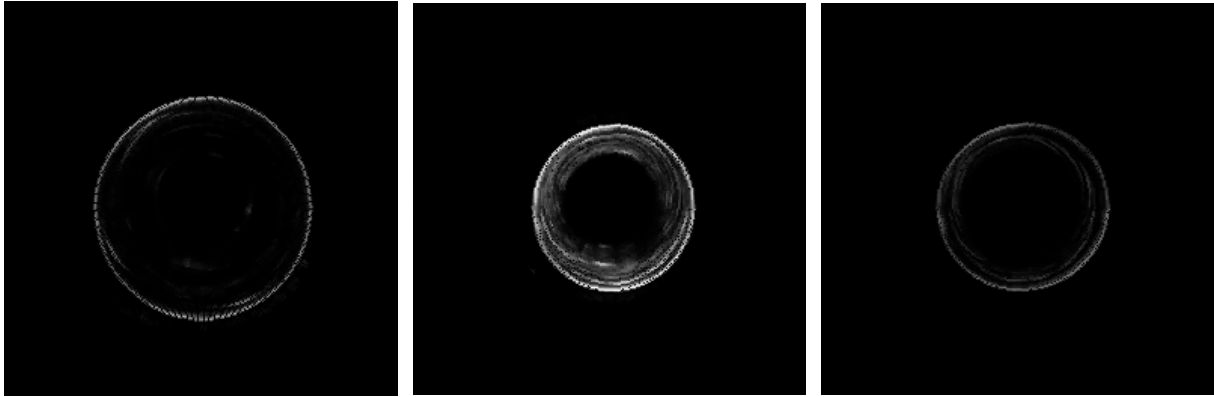


**Figure 11:** Actual saw handle with physical measurements for validation.

The wall thickness of the saw handle as visualized in the reconstructed images may be misleading because it does not correspond to the actual physical properties of the object. Rather, it depends on the thickness of the bright area corresponding to the surface of the object in the ultrasound image. Furthermore, the roughness along the surface of the reconstructed images is due to the presence of noise close to the surface of the object and possible limitations of the interpolation method.

The number of triangles used to render the surface may be used to get an idea of the surface roughness. The reconstruction of the saw handle with offset had 144131 number of vertices and 284280 number of triangles. The processing time for a complete 3D reconstruction was

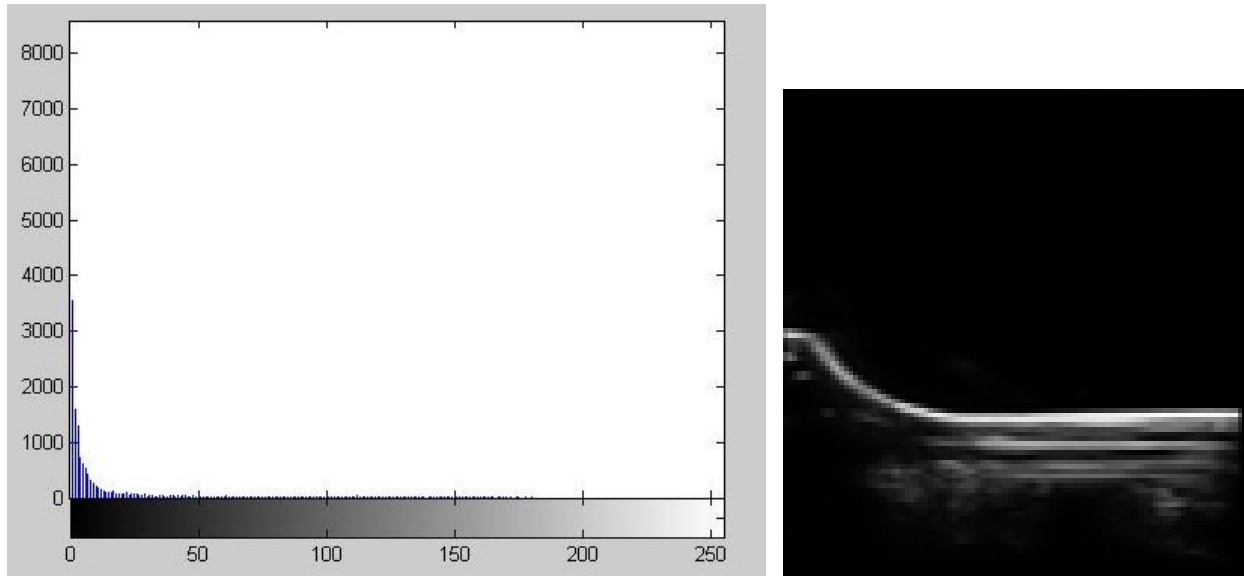
72.376760 seconds. The reconstruction with no offset had 68664 number of vertices and 135054 number of triangles with 55.959576 seconds elapsing time. As the reconstruction was completed, there were 98 slices that were interpolated to form a 3D volume. Figure 12 shows examples of the slices 1, 50 and 98.



**Figure 12:** Interpolated slices 1, 50 and 98 respectively. These slices were used for the complete 3D reconstruction.

To demonstrate the graphical representation of the tonal distribution of the reconstructed volume, one of the image used for the 3D reconstruction is examined below (figure 13). The histogram can be used to evaluate the distribution of the intensities in the image and to evaluate the number of pixels having each intensity.





**Figure 13:** Histogram of a typical image used for the 3D reconstruction. The histogram represents the intensities present in the image divided in 50 bins.

### **Limitation of the 3D Reconstruction Algorithm**

The accuracy of the algorithm depends on how accurately the images are acquired at the each angle. Furthermore, if there are two or more objects in the image, this algorithm may not be able to reconstruct all individual objects completely and accurately. If there are holes or defects on the object's surface, the algorithm would treat them as an empty space in the reconstruction and may not reconstruct them properly. To determine the dimensions of the object, manual calculation of centimeter to pixel needs to be done and the final dimensions need to be entered in the algorithm. Finally, to apply this algorithm to real tissues, a segmentation method may need to be used prior to the 3D reconstruction.

## **CHPATER IV**

### **CONCLUSION**

An ever growing number of clinical scenarios have shown the benefits of using 3D ultrasound as a promising tool for its flexibility and accuracy. It is often difficult to analyze the anatomy of a structure from 2D images. Hence, 3D reconstruction algorithms are becoming increasingly popular. This study reports a 3D reconstruction algorithm that can be used to reconstruct volumes from 2D ultrasound images obtained at different insonicating angles. The feasibility of this algorithm is tested using real experimental data. The results of this study shows a good agreement between the 3D reconstructions obtained using the proposed algorithm and the physical dimensions of the object being investigated. In the future, this algorithm should be tested with tissue data. If successful, it may provide a tool for 3D ultrasound reconstructions based on data acquired using rotational scanners.

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